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Connectivity Alternatives for Remote Users of the Maintenance Processor Subsystem (MPS)

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16. Abstract

Preliminary testing has shown that utilizing commercial off-the-shelf equipment to implement x.25 packet assembly and disassembly for Remote Maintenance Monitoring terminal connectivity is far superior to the method described in EEM.6140.4 Chapter 7. This approach yields an expected life cycle cost savings in excess of $37,000.00 per installation. Additionally, reliability, data transparency, and response time are improved, while space and cabling requirements are significantly reduced. This testing also showed potential for even greater cost savings and improved functionality by increasing the bandwidth and replacing the RS-232 standard connection with a V.35 connection. A follow-up report will be issued at the conclusion of tests conducted to determine the viability of this alternative when the communications load is increased significantly and the bandwidth changed accordingly.

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EXECUTIVE SUMMARY

This report describes the preliminary results of tests conducted into alternative approaches for connecting end users to the Maintenance Processor Subsystem (MPS) through the Paradyne DCX statistical multiplexer network. As more information is available and further tests are conducted, a follow-up document will be prepared for publication. The Paradyne network provides the link between the asynchronous communications lines (the Remote Maintenance Monitoring System (RMMS) users) to the MPSs located at the Air Route Traffic Control Centers (ARTCCs). The MPS ingests, stores, and processes Maintenance Management System (MMS)/Interim Monitor and Control Software ((I)MCS) data and Remote Monitoring Subsystem (RMS) data.

The current configuration recommended in the Electronic Equipment Modification (EEM) Handbook Order 6140.4, Chapter 7 (revised) requires each asynchronous line to have an individual connection from the MPS to the multiplexer. The results of analyzing alternatives to this configuration indicate that not only can a significant cost savings be realized, but fault tolerance, functionality, and response time can all be improved.

The alternative that provides the greatest benefit includes replacing the individual asynchronous connections from the MPS to the multiplexer with an X.25 interface. This interface allows multiple channels to be transmitted over a single communication line, reducing the number of cables required for connection and the number of chassis required for housing the multiplexer equipment. Alterations to the current configuration require replacing the individual multiplexer ports with a commercially available X.25 interface and replacing the Tandem 6100E CSS with the Tandem 6105 Communications Controller (CC). The overall cost savings realized by this configuration, based on a 7-year life cycle, is $932,363 for the 25 sites. A higher degree of fault tolerance is achieved by providing hardware redundancy. Elimination of the 6100E CSS reduces the requirement for floor space by 21 square feet per site. The band width for the X.25 link is higher than the asynchronous line which, in turn, decreases user response time. The X.25 link increases the functionality of the overall system by eliminating a number of existing data control problems.

The 7-year equipment life cycle costs for acquisition, installation, and maintenance of this alternative resulting in an overall cost reduction of $932,350 over 25 sites are described below:

Life Cycle Costs Per Site	Savings
Equipment acquisition (nonrecurring)	$25,147
Maintenance	7,345
Cooling and Power	4,802
Total	$37,294

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An improved degree of fault tolerance is provided by the X.25/6105 CC alternative through hardware redundancy. Should an MPS port failure occur, lines supporting direct connect printers can be rerouted to another port by the X.25 interface resulting in no loss of service. In addition, users will not be denied service after a DCX 850 port failure due to a lack of ports because the lines affected by a failure can be multiplexed over the remaining ports.

Replacing the 6100E CSS with the 6105 CC reduces the floor space required for the Tandem equipment. The 6105 CC resides in the existing MPS host I/O chassis; therefore, 21 square feet of floor space needed for the 6100E CSS cabinet is eliminated at each site.

The above was verified by preliminary testing at the Federal Aviation Administration (FAA) Technical Center, Atlantic City International Airport, NJ. An empirical evaluation of the X.25/6105 CC alternative indicated that complete functionality of the MPS is maintained, a number of existing data control problems are eliminated, and response time was improved when measured in the testbed supporting three users.

Under these loading conditions, a 10 percent improvement in response time was achieved. As the number of users being supported and the number of transactions increases, additional system overhead will be induced. However, system overhead problems can be ameliorated by proper, judicious selection of bandwidth. As previously mentioned, these results are considered preliminary, and a follow-up report will be generated after loading conditions have been increased and a new bandwidth selected.

In summary, use of the X.25/6105 CC alternative provides significant reductions in hardware acquisition and installation costs, reductions in power and cooling costs, increased availability of floor space, and an improved degree of fault tolerance. All of these benefits are achieved while maintaining MPS functionality, eliminating a number of existing data control problems, and maintaining or potentially improving user response time.

1. INTRODUCTION.

1.1 PURPOSE.

The purpose of this report is to present a preliminary study of alternative approaches for connecting end users to the Maintenance Processor Subsystem (MPS) located at the Air Route Traffic Control Centers (ARTCCs). As more information is available and further tests are conducted, a follow-up document will be prepared for publication. The evaluation of alternatives is based upon potential reductions in acquisition, installation, and/or operating costs, and the minimization of floor space requirements. These reductions must be achieved, however, while maintaining or improving system functionality, performance, and fault tolerance.

1.2 SCOPE.

Alternative approaches are compared to the baseline configuration described in the Electronic Equipment Modification (EEM) Handbook (Order 6140.4, Chapter 7, Change 9). Each alternative is evaluated relative to life cycle costs, fault tolerance, and functionality/performance.

Life cycle costs are evaluated over a 7-year period in terms of nonrecurring costs for equipment (i.e., hardware and software) acquisition and installation and in terms of recurring costs for equipment maintenance and operations (i.e., floor space, cooling, power, and system management).

Fault tolerance is evaluated qualitatively rather than quantitatively. Differences in the ability of each alternative to accommodate fault conditions are identified and the impact discussed.

Functionality and performance are evaluated in terms of the ability of each alternative to meet MPS requirements and the extent to which these capabilities can be demonstrated. Functionality is defined as remote user access to applications running on the MPS as verified by the Maintenance Data Terminal (MDT) Test Plan. Performance is defined as the ability of the system to maintain response time under varying traffic workloads.

1.3 ORGANIZATION OF REPORT.

The remainder of this report provides detailed technical information regarding the connectivity issue under review. Section 2, "Technical Background," includes a description of the EEM recommended configuration, a definition of the connectivity issue under review, and a list of assumptions from which alternatives were developed. Section 3, "Description of Alternatives," includes a description of a Proposed Modified EEM Configuration alternative,

a description of the X.25/6105 Communications Controller (CC) alternative, and a brief review of other alternatives which were considered but did not meet the specified requirements. Section 4, "Cost Analysis," includes a detailed cost analysis of the Proposed Modified EEM Configuration alternative, the X.25/6105 CC alternative, operational costs, floor space savings, and an analysis of minor impact factors. Section 5, "Fault Tolerance Analysis," includes a description of the Fault Tolerance Analysis, an analysis of the Proposed Modified EEM Configuration alternative, and an analysis of the X.25/6105 CC alternative. Section 6, "Preliminary Testing," provides information regarding testing conducted at the FAA Technical Center for the alternatives under consideration and their results. Section 7, "Conclusions and Recommendations," provides a summation of the major conclusions of this analysis and corresponding recommendations.

2. TECHNICAL BACKGROUND.

2.1 EEM CONFIGURATION.

As shown in figure 2-1, the communications equipment required to provide connectivity between the asynchronous communications lines and the MPS consists of a Tandem 6100E Communications Subsystem (CSS) and a Paradyne DCX 850 multiplexing system. The 6100E CSS and the DCX 850 are interconnected using an average of 64 RS-232 cables. The DCX 850 is connected to the asynchronous communications lines via a wide area Data Multiplexing Network (DMN). The 6100E CSS is currently located on the first floor of the ARTCC while the DCX 850 is located in the basement. Future plans call for the 6100E CSS to also be moved to the basement.

A 6100E CSS cabinet (Model 6101E) may contain one to three CSS units (Units A, B, and C) as shown in figure 2-1. Each CSS unit is capable of supporting a maximum of 15 LIUs. The LIU provides the interface for the RS-232 cables used to connect the 6100E CSS and the DCX 850. The LIU consists of a Line Interface Module (LIM) and a Communications Line Interface Processor (CLIP). The LIM handles the physical layer processing (International Standards Organization (ISO) Open Systems Interconnection (OSI) layer 1) while the CLIP handles the data link layer processing (OSI layer 2). The terminal handling processing (OSI layer 3) is performed by the MPS CPU using TERMPROCESS software. LIUs are available in two versions: LIU1 and LIU4. The LIU1 is a general-purpose LIU designed to run all available 6100E CSS protocols and supports one line in any mode of operation. LIU1s can be configured to run either asynchronous (50 bites per second (bps) to 19.2 kilobits per second (kbps)), byte synchronous (up to 19.2 kbps), or bit synchronous (up to 56 kbps) communications. The LIU4 is a special purpose LIU which uses the ATP6100 protocol and supports up to four communications lines. The LIU4 supports asynchronous point-to-point communications only.
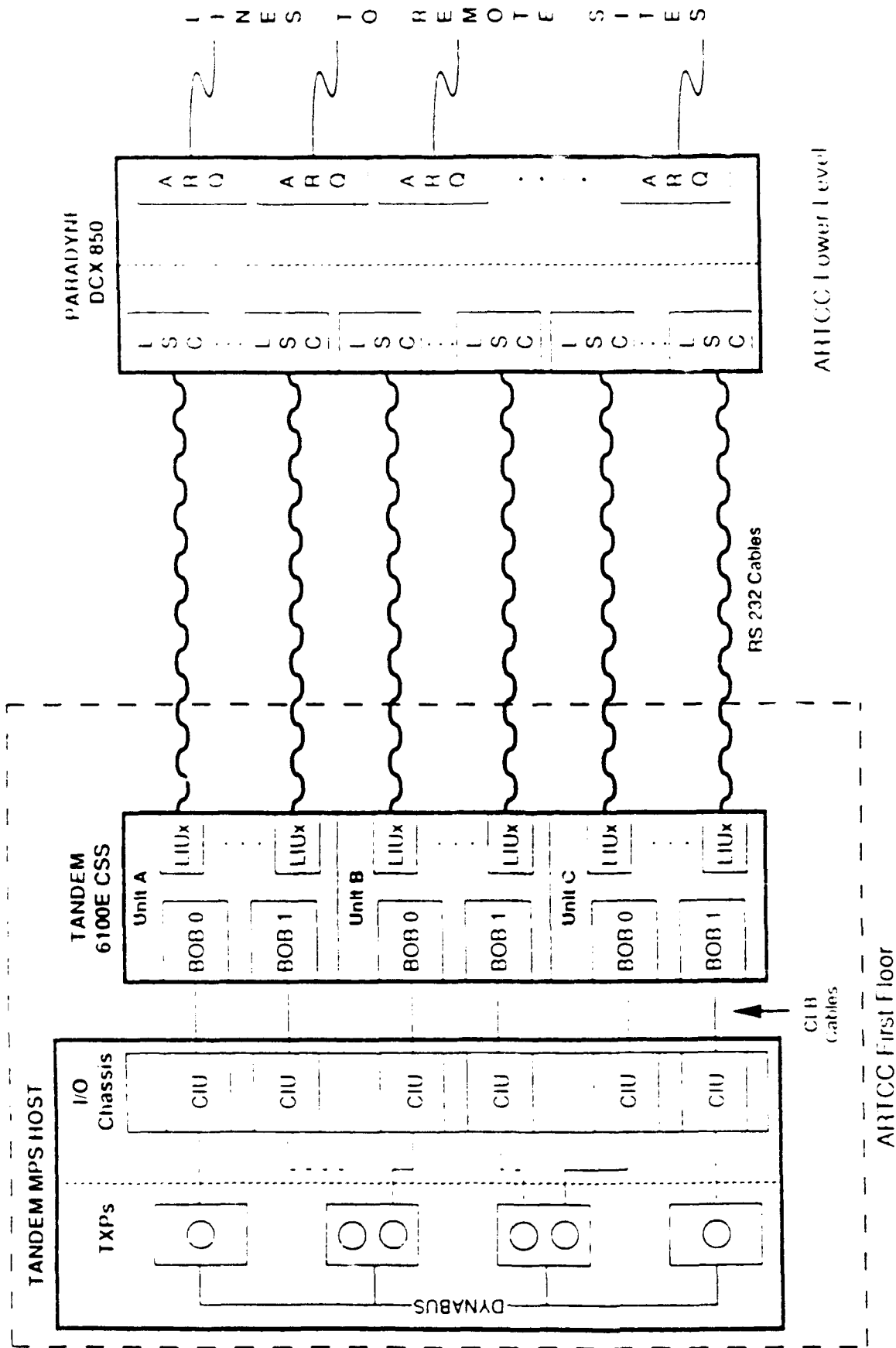
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FIGURE 2-1. EEM RECOMMENDED CONFIGURATION

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The 6100E CSS cabinets at the ARTCCs are fully populated in that each cabinet contains three CSS units and each CSS unit contains 15 LIUs. Of the 45 LIUs contained in the ARTCC cabinet configuration, 8 are LIU4s and 37 are LIU1s. Therefore, each 6100E CSS cabinet provides 69 available communications ports.

Two Communications Interface Units (CIUs) in the MPS Input/Output (I/O) chassis provide the interface between each CSS unit and the MPS. The MPS communicates with the 6100E CSS using a dual high speed full duplex serial cable operating at a 1 megabit per second data rate using a Tandem proprietary protocol. This communications link is referred to as the CIU-to-LIU BUS (CLB). A 4-wire shielded copper cable connects each of the CIUs in the MPS I/O chassis to one of two breakout board line interface modules (BLIMs) in the CSS unit. The BLIM is connected to the breakout board (BOB) and both are functionally interdependent components. The BLIM provides the BOB with the mechanical connection to the CLB. The BOB is responsible for breaking out interleaved CLB traffic as well as monitoring and controlling the CSS power supplies. To provide fault tolerance, each CSS unit has two BOBs which are connected by two CLB cables to the two CIUs in the MPS I/O chassis.

The communications lines from the DMN connect to a Paradyne DCX 850 multiplexing system as shown in figure 2-1. All ARTCC sites have at least one DCX 850. The remote maintenance data terminals (MDTs) communicate using 2400 bps asynchronous ports. Attached printers, meaning those controlled by the MDT, do not communicate directly with the MPS. Both the MDTs and the attached printers communicate with the MPS through a pool of available DMN ports assigned to remote users. Direct connect printers, meaning those controlled by the MPS and connected by a dedicated line, communicate using 1200 bps asynchronous ports.

The DCX 850 contains one Composite-Link card (ARQ) for each remote communications line. The DCX 850 currently contains Low Speed Channel (LSC) Port cards each of which provides four interfaces for the RS-232 cable links to the 6100E CSS. When a remote MDT user establishes a connection to the MPS, one DCX 850-to-6100E CSS RS-232 physical link is dedicated for the duration of a session. There is no logical multiplexing of connections over the physical link during the session. When the connection is terminated, the physical link is made available for other remote MDT users.

2.2 DEFINITION OF CONNECTIVITY ISSUE.

Although the EEM configuration is viable, it is expensive and requires a large amount of floor space. Thus, for an alternative approach to be viable, it must reduce costs and floor space requirements. These reductions must be achieved, however, while maintaining or improving system functionality, performance, and fault tolerance.

For the purpose of this analysis, system functionality is defined as remote MDT user access to applications running on the MPS as verified by the MDT Test Plan. The relevant performance metric is the difference in time stamps between the beginning transmission of an input message and the receipt of a corresponding response message. Performance is defined as the ability of the system to maintain response time under varying traffic workloads. Fault tolerance is defined as the ability of the system to maintain user access and data integrity during component failure. It is important to evaluate performance and fault tolerance factors along with system functionality because they may affect system response time and availability.

2.3 ASSUMPTIONS.

The following assumptions were made in the formulation and analysis of alternatives:

   a. The number of sites to be considered is 25, including all 23 ARTCC sites; the FAA Technical Center, Atlantic City International Airport, NJ; and the FAA Academy, Oklahoma City, OK.

   b. The average number of remote communications lines terminating at the MPS is 64 per site.

   c. Recurring costs should be discounted to present worth using a one percent per month rate.

   d. The average distance between the Paradyne DCX 850 in the ARTCC basement and the MPS on the first floor is 300 feet. This distance is a national average and is not specific to any particular site.

   e. "Unused capacity" in existing equipment can be utilized for other applications (e.g., if only 20 slots in a 40 slot cabinet are used, only one-half the cost of the cabinet need be included). The full cost of new equipment must be included regardless of the degree of utilization.

   f. If existing equipment is no longer required, it may either be utilized for other applications or returned to the vendor for a credit.

The analysis of minor impact factors is discussed in section 4.5, "Analysis of Minor Impact Factors." Other assumptions, relevant to only a particular part of the analysis, are specified in the appropriate section.

3. DESCRIPTION OF ALTERNATIVES.

In this section alternatives to the recommended EEM configuration
will be discussed. Alternatives which were considered viable for
this evaluation and are discussed in detail include the Proposed
Modified EEM Configuration alternative and the X.25/6105 CC
alternative. As previously discussed, for an alternative to be
viable, it must reduce costs and floor space requirements. These
reductions must be achieved, however, while maintaining or
improving system functionality, performance, and fault tolerance.
Alternatives which were not considered viable for this evaluation
are discussed briefly and include the X.25/6100E CSS alternative
and the DCX 850-6100E CSS Connection with Fiber Optic Multiplexers
alternative.

3.1 PROPOSED MODIFIED EEM CONFIGURATION ALTERNATIVE.

As previously discussed in section 2.1, in the current EEM
configuration the 6100E CSS is connected to the DCX 850 with RS-
232 cables. The EEM configuration requires 64 cables to connect
the LIUs in the 6100E CSS to the LSCs in the DCX 850. The average
distance between the 6100E CSS on the first floor to the DCX 850
in the basement is 300 feet.

As previously discussed, future plans require the relocation of the
6100E CSS from the first floor to the basement. This would reduce
the number of cables to be pulled from the first floor to the
basement from 64 LIU-to-LSC cables to six CLB cables. The maximum
allowable length for the copper CLB cables, however, is 150 feet.

In the Proposed Modified EEM Configuration alternative, the CLB
cabling restriction would be overcome by replacing each existing
copper CLB cable with two fiber optic multiplexers and fiber optic
cables. The maximum allowable length for the fiber optic cables
is 1600 feet. As shown in figure 3-1, this alternative is very
similar to the recommended EEM configuration.

Benefits of the Proposed Modified EEM Configuration alternative
include:

        a. The number of cables which must be pulled between the
first floor and the basement would be reduced from 64 to 6.

        b. The available square footage on the first floor would be
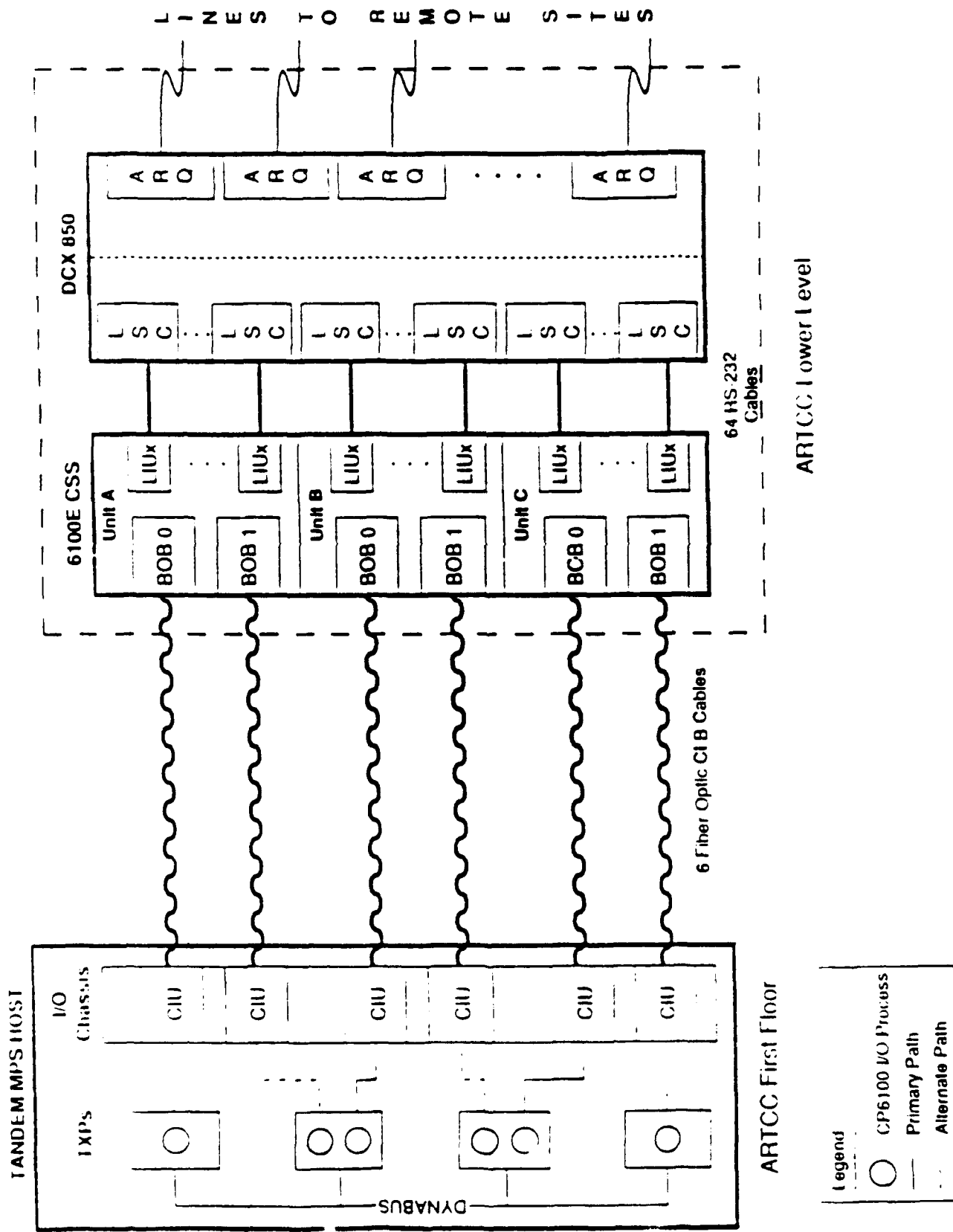increased.

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FIGURE 3-1. MODIFIED EEM RECOMMENDED CONFIGURATION

Disadvantages of the Proposed Modified EEM Configuration alternative include:

a. There would be an increase in system cost due to the acquisition of fiber optic cabling and two fiber optic multiplexers per cable.

b. System fault tolerance would be reduced and maintenance costs would be increased because 12 active components and their associated connections would be added to the system configuration.

3.2 X.25/6105 CC ALTERNATIVE.

In the X.25/6105 CC alternative, the 6100E CSS is replaced with two 6105 CCs as shown in figure 3-2. Each 6105 CC contains four LIU1 ports and resides in the MPS I/O chassis. In this alternative only two of the four LIU1 ports will be used, thus, providing built-in spares. The 6105 CC is connected to two different MPSs, a primary and an alternate, providing redundancy.

Four X-GATE cards replace the LSC cards in the DCX 850. Although the X-GATE cards can multiplex up to 64 virtual circuits onto one X.25 link, Paradyne recommends that each X-GATE card support no more than 32 virtual circuits for this application using an interconnect bandwidth of 19.2 kbps. Although only two X-GATE cards are required to support the assumed number of connections (i.e., 64 connections), a third and fourth card were added to this configuration to enhance fault tolerance. Two X-GATE cards are connected to each 6105 CC which, because of its processing redundancy described above, provides additional fault tolerance to this configuration.

Information is sent from the 6105 CC on the first floor to the DCX 850 in the basement using the X.25 protocol at a rate of 19.2 kbps using RS-232. Lower capacitance Extended Distance Data cable (EDDC) is used instead of standard twisted pair cable because the 6105 CC and the DCX 850 are 300 feet apart. It has been demonstrated, through testing at the FAA Technical Center, that the EDDC cable is capable of performing at the required speed and distance.

3.3 OTHER ALTERNATIVES.

Several other alternatives were considered for this evaluation but, because they did not provide the cost or floor space reductions provided by the X.25/6105 CC alternative, they were not investigated further. In addition, these alternatives also reduced fault tolerance and increased maintenance costs because they required the addition of more active components to the system. Two of these discarded alternatives are briefly described below.
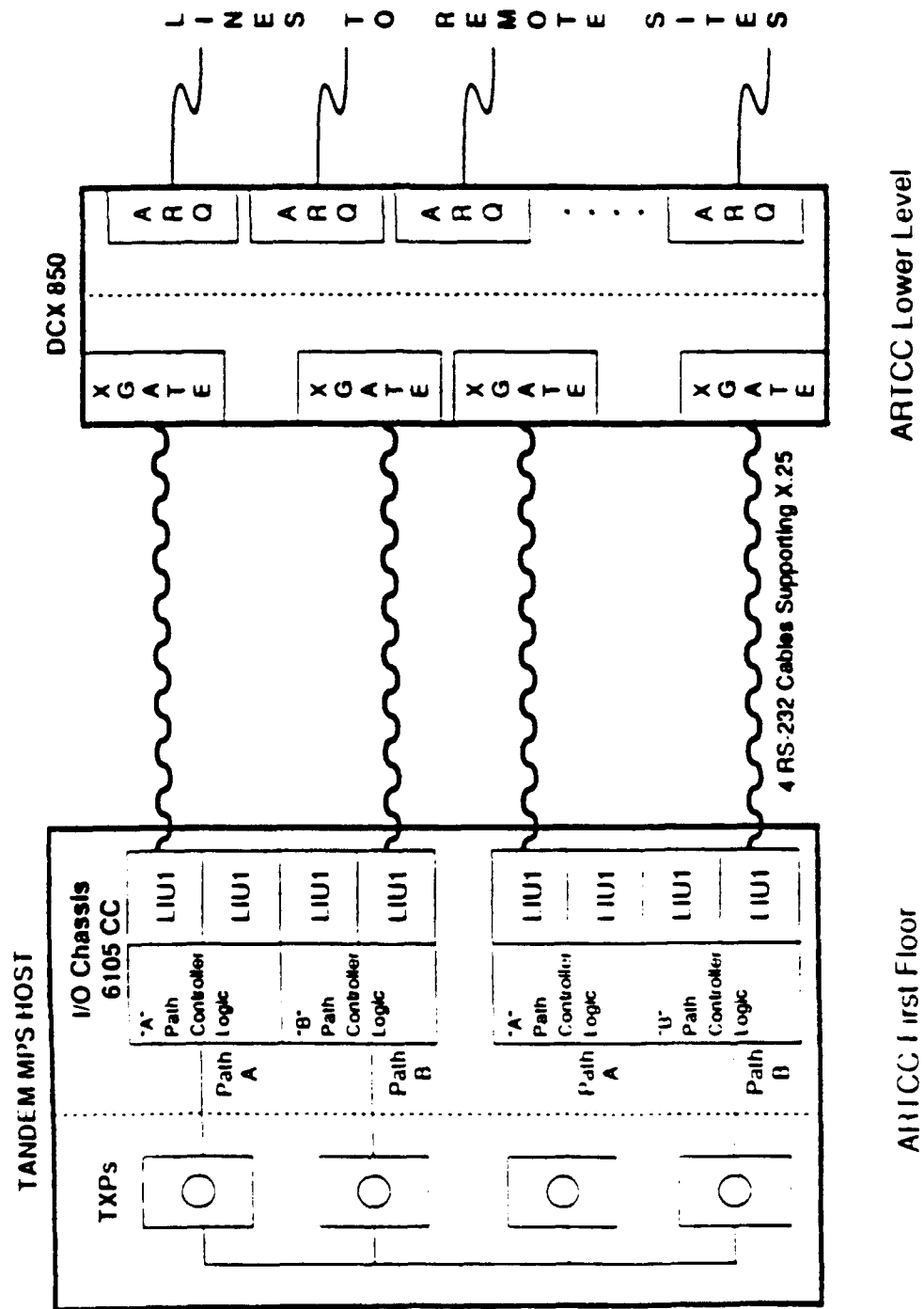
FIGURE 3-2. X.25 INTERFACE/6105 CC ALTERNATIVE

3.3.1 X.25/6100E CSS Alternative.

As shown in figure 3-3, this alternative describes the use of the X.25 Interface with the 6100E CSS to reduce the number of links between the 6100E CSS and the DCX 850. In this configuration both the 6100E CSS and the DCX 850 are located in the basement. An X-GATE card is connected to an LIU1 in each of the three CSS units. The 6100E CSS is connected to two different MPSs, a primary and an alternate, providing redundancy.

This alternative was eliminated for the following reasons:

   a. The cost of the 6100E CSS would make this alternative less cost effective than those utilizing the 6105 CC.

   b. There would be no reductions in floor space requirements because this alternative utilizes the 6100E CSS.

   c. Because the average distance between the 6100E CSS and the MPS is 300 feet, this alternative would require the use of fiber optic multiplexers and cables. This requirement would add fiber optic conversion costs to this alternative.

   d. System fault tolerance would be reduced and maintenance costs would be increased because 12 active components and their associated physical connections would be added to the system configuration.

3.3.2 DCX 850-6100E CSS Connection with Fiber Optic Multiplexers.

As shown in figure 3-4, fiber optic cables would be used to connect the 6100E CSS on the first floor with the DCX 850 in the basement. This option was considered because the cost and complexity of the wiring installation between the first floor and the basement would be reduced.

This alternative was eliminated for the following reasons:

   a. The cost of the 6100E CSS would make this alternative less cost effective than those utilizing the 6105 CC.

   b. There would be no reductions in floor space requirements because this alternative utilizes the 6100E CSS.

   c. Because the average distance between the 6100E CSS and the DCX 850 is 300 feet, this alternative would require the use of fiber optic multiplexers and cables. This requirement would add fiber optic conversion costs to the alternative.
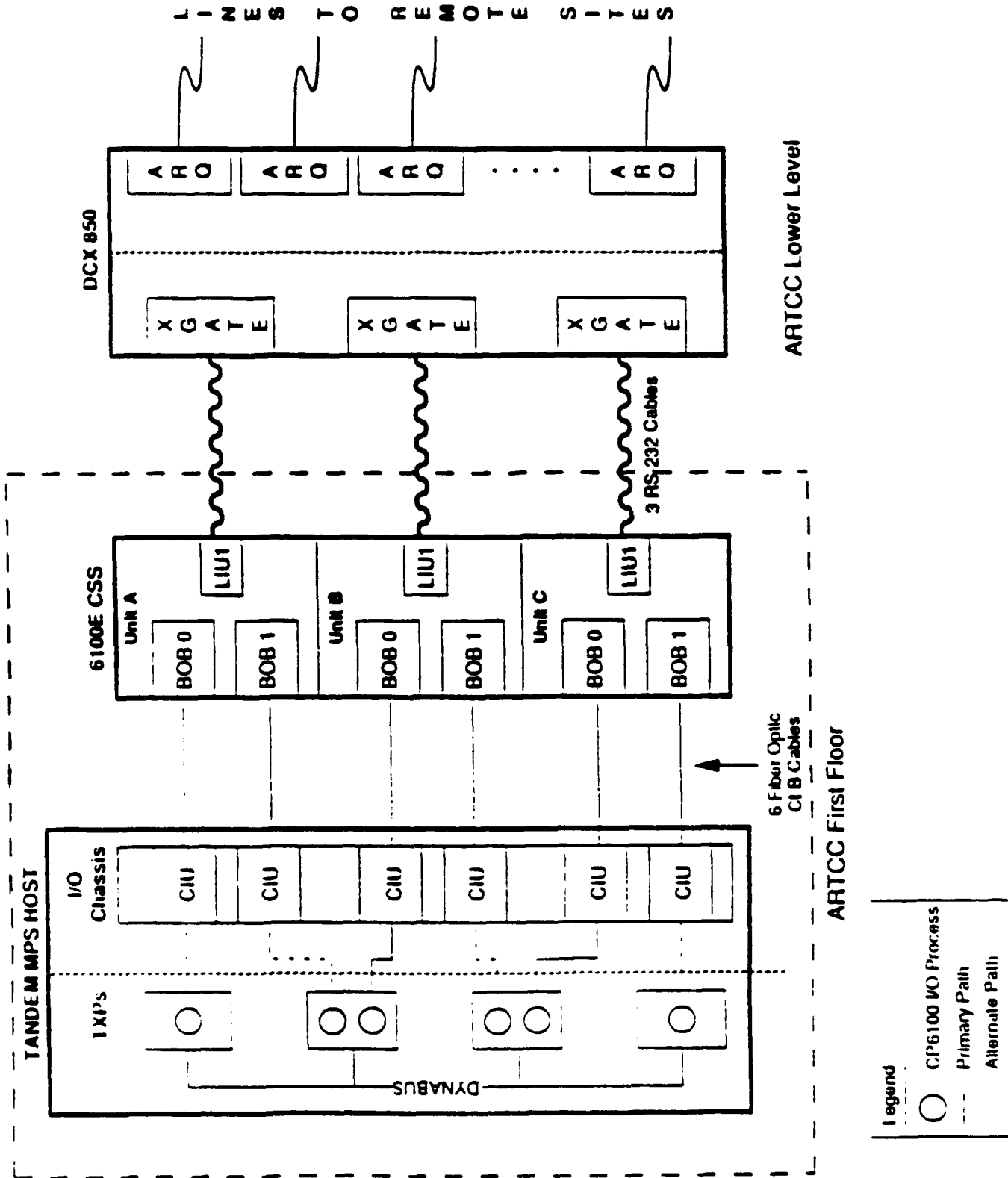
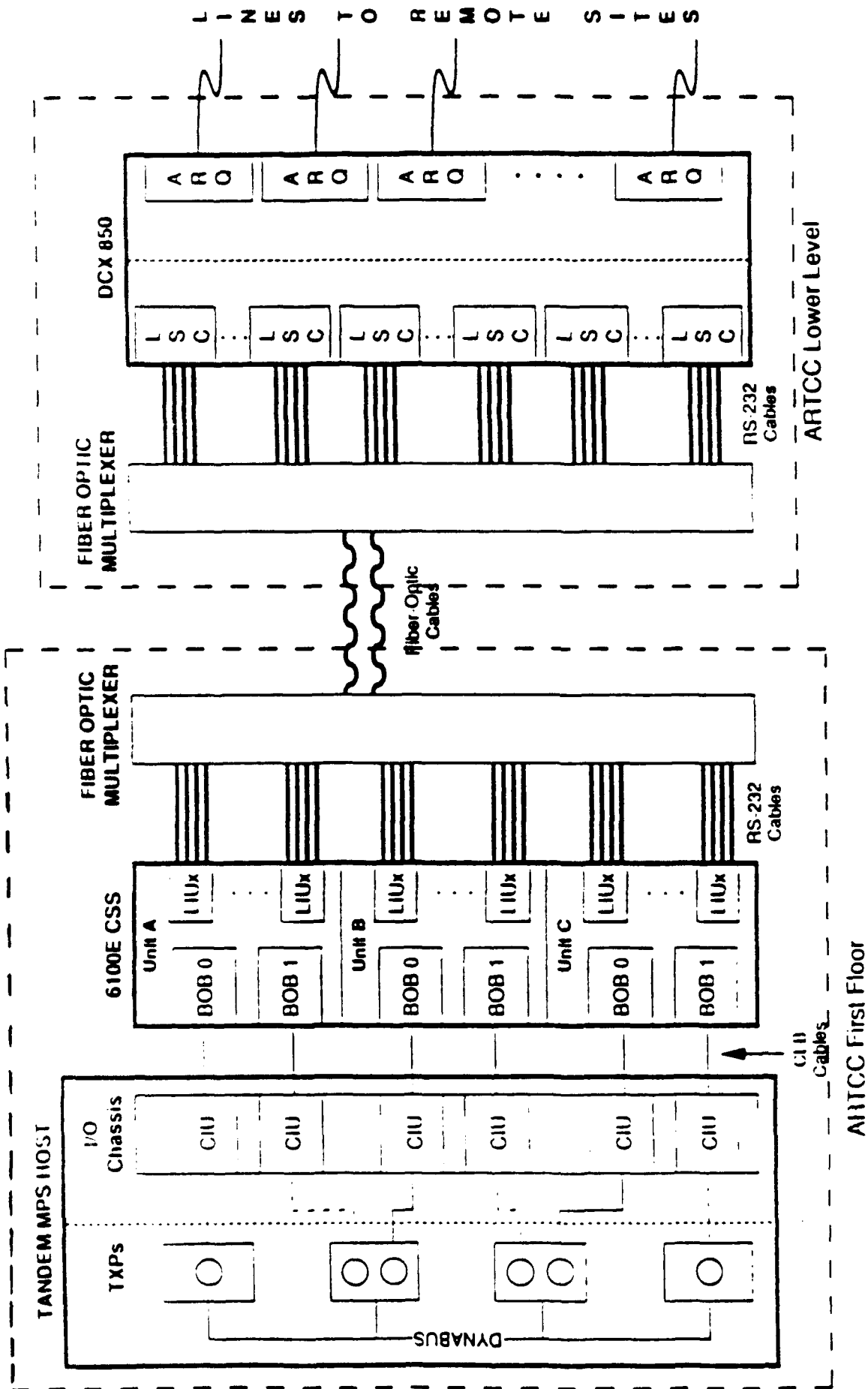FIGURE 3-3. X.25 INTERFACE/6100E CSS ALTERNATIVE

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FIGURE 3-4. FIBER OPTIC MULTIPLEXER ALTERNATIVE

d. System fault tolerance would be reduced and maintenance costs would be increased because 12 active components and their associated physical connections would be added to the system configuration.

4. COST ANALYSIS.

This section provides the cost comparison between the Proposed Modified EEM Configuration alternative and the X.25/6105 CC alternative. This cost comparison is based upon a 7-year life cycle and includes equipment acquisition, installation, and maintenance costs. Additional information regarding the assumptions used in developing cost estimates, operational costs, and an analysis of minor impact factors are also provided in this section.

4.1 ASSUMPTIONS.

The following assumptions were made in the formulation and analysis of cost estimates:

a. The General Services Administration (GSA) purchase price for all Paradyne and Tandem equipment includes shipping charges and all Tandem equipment includes installation charges. The Paradyne charge for installation is $250 per cabinet regardless of its contents.

b. All other purchase prices are based on preliminary discount price estimates provided by the vendor. These prices are based upon order quantities for 25 sites.

c. The annual equipment maintenance cost estimates for Paradyne and Tandem equipment are based on GSA schedules for Zone A service (i.e., 0-50 miles from the vendor service office).

d. Installation not done by the vendors as part of equipment delivery will be done by the FAA. The estimated cost for this labor is $45 per hour.

4.2 PROPOSED MODIFIED EEM CONFIGURATION ALTERNATIVE.

To implement the Proposed Modified EEM Configuration alternative as shown in figure 3-1, the following equipment is required:

a. One Tandem 6100E CSS

b. One Paradyne DCX 850 cabinet

c. Sixty-four RS-232 Cables to connect the 6100E CSS and the DCX 850

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d. Six full duplex fiber optic cables with two fiber optic connectors per cable to connect the 6100E CSS to the MPS.

The purchase, installation, maintenance, and life cycle costs per site for this alternative are summarized in table 4-1. The total per-site nonrecurring cost for equipment acquisition and installation labor is $59,243. The recurring maintenance cost is $326 per month. This calculates to a 7-year life cycle cost of $77,662 per site. The total life cycle cost for 25 sites is $1,941,550.

To compute the cost of the 6100E CSS, the cost of a fully loaded cabinet is computed and prorated to accommodate 64 lines. The cost of the 6100E CSS depends upon the mix of LIU1s and LIU4s. The cost of the LIU1 and LIU4 are roughly the same ($1,325). Therefore, on a cost per port basis, the LIU4 is four times less expensive than the LIU1. In addition to being cost effective, the LIU4 supports the block mode protocol needed for the 6100E CSS to communicate with the LSC cards in the DCX 850. In order to determine the cost of providing 64 ports, the cost of a 6100E CSS containing two CSS units with 15 LIU4s is computed. This computation, which calculates the cost for 120 ports, is then prorated to compute the cost for 64 ports. As summarized in table 4-1, the prorated cost of the 6100E CSS is $32,697.

The Tandem maintenance costs are based on the specific components being serviced. As summarized in table 4-1, the cost for a fully populated 6100E CSS supporting 120 ports is $421 per month. The prorated cost for 64 ports is $225 per month.

The DCX 850 system consists of a main chassis and three expansion chassis. The following cards are resident in the main chassis:

Card	Description	Quantity
STC	System Timing Card	1 per system
64K	Buffer Card	1 per system
USO	User Switching Option	1 per system
MCO	Multiplexer Control Option	1 per system
BEM	Bus Expansion Module	1 per chassis
ARQ	Line Interface/Composite Card	1 per line

The main chassis may contain up to 16 cards excluding the System Timing Card (STC). This leaves room for up to 12 ARQs in the main chassis. Most ARTCC DCX cabinets are configured to allow three expansion chassis. The main chassis, therefore, contains three Bus Expansion Module (BEM) cards.

TABLE 4-1.   MODIFIED EEM ALTERNATIVE

DESCRIPTION	Purchase Unit Cost	Qty	Purchase Total Cost	Monthly Maintenance Unit Cost	Total Cost	7-Year Life Cycle
Cabling						
RS-232 cables 20 feet	10	64	640	n/a		
Fiber Optic Multiplexer	298	12	3,576			
Duplex Fiber Cable 300'	350	6	2,100	n/a		
FAA Installation						
Fiber (6 ports, 6 Hr/Port)	45	36	1,620	n/a		
RS-232 (64 ports, 2 Hr/port)	45	128	5,760	n/a		
Tandem 6100						
Base Cabinet and Unit A (15 slots)	12,602	1	12,6)2	119	119	
Unit B (15 slots)	9,014	1	9,014	92	92	
LIU1 Cards	1,325	0	0	7	0	
LIU4 Cards (4 ports per card)	1,323	30	39,690	7	210	
Total (120 ports)			61,306		421	
Prorate (64 ports)			32,697		225	
Paradyne DCX						
Paradyne DCX Expansion						
Expansion Chassis	3,000	1	3,000		101	
Installation	250	1	250			
LSC Cards	600	16	9,600			
Cost per Site			$59,243		$326	$77,662
Cost for 25 Sites			$1,481,075		$8,150	$1,941,550

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The expansion chassis, containing the second through fourth bays, is used to house the DCX LSC cards. Each LSC card provides four asynchronous ports. Each expansion chassis may house 16 cards, excluding the Bus Timing Module (BTM), providing for a maximum of 16 LSC cards or 64 ports per chassis.

To compare alternatives, it is not necessary to compute costs of the common components (i.e., the main chassis and cards resident in it). It is only necessary to compute the cost of one expansion cabinet and the LSC cards. As summarized in table 4-1, the cost of the chassis is $3,000, the cost of 16 LSC cards is $9,600, and installation is $250.

The Paradyne maintenance charges for a DCX expansion chassis are independent of the number of cards in the chassis. The maintenance cost for an expansion chassis is $101 per month.

Sixty-four RS-232 cables are required to connect the LSCs in the DCX 850 with the LIUs in the 6100E CSS. Since these components will be resident in the basement, cable runs will be shorter and installation relatively simple. It is assumed that the cables are 20 feet in length and the average time to install, terminate, and test is 2 hours. As shown in table 4-1, the resulting cost for 64 ports is $5,760 for labor and $640 for cables.

Fiber optic CLB cables are required to connect the 6100E CSS in the basement with the MPS on the first floor. The installation cost of the fiber optic cables will vary from site to site as a function of the following variables:

    a. Length of the cabling required
    b. Congestion of the cable path
    c. Number of cables pulled per session
    d. Congestion of the two termination ports.

Six duplex fiber optic cables are used to simplify installation. It is assumed that all six duplex cables can be pulled at the same time. As shown in table 4-1, the resulting purchase cost of the cables is $2,100. The time required for installation, termination, and test is 36 hours, resulting in a cost of $1,620.

4.3 X.25/6105 CC ALTERNATIVE.

To implement the X.25/6105 CC alternative as shown in figure 3-2, the following equipment is required:

    a. Two Tandem 6105 CC boards

    b. One DCX 850 with four X-GATE cards

    c. Four EDDC low capacitance cables to connect the 6105 CCs with the DCX 850.

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The purchase, installation, maintenance, and life cycle costs per site for this alternative are summarized in table 4-2. The total per-site nonrecurring cost for equipment acquisition and installation labor is $34,096. The recurring maintenance cost is $152 per month. This calculates to a 7-year life cycle cost of $45,170 per site. The total life cycle cost for 25 sites is $1,129,250.

In this alternative, 6105 CC boards are installed in the MPS I/O chassis. Only two of the available four ports on each 6105 CC are used leaving the option open for utilization of these ports for other options or as spares. However, their use is uncertain so the costs for the 6105 CCs are not prorated. As summarized in table 4-2, the cost for the 6105 CCs is $8,236. The maintenance cost for the 6105 CCs is $44.

The acquisition cost for the DCX 850 is $4,250, installation is $250, and the maintenance cost is $152 per month. Since a new chassis will be required, these costs are not prorated. The acquisition cost of the Paradyne X-GATE cards is $4,800 each. Maintenance of the X-GATE cards is included as part of the chassis maintenance.

The EDDC cables will have to be installed by FAA personnel. The installation of the EDDC cables will require running cables from the DCX 850 in the basement to the MPS I/O chassis on the first floor. All four cables will be pulled in parallel. The installation time per EDDC cable is assumed to be equivalent to the 8 hours required for the fiber optic cables in the Proposed Modified EEM Configuration alternative. The resulting installation cost is $1,440.

4.4 OPERATIONAL COSTS.

In this section operational costs are analyzed for each alternative including cooling costs, power costs, and floor space requirements. The results of the analysis indicate that, by using 6105 CCs with an X.25 interface, operational costs are estimated to be reduced as follows:

    a. Power cost will be reduced by $24 per month.
    b. Cooling cost will be reduced by $66 per month.
    c. Floor space will be reduced by 21 square feet.

The underlying assumptions and methods for computing these reductions, as summarized in table 4-3, are presented below.

The 6100E CSS requires a continuous, stable, 3-phase AC input power source free from electrical noise. This is often referred to as "conditioned power." Tandem publications do not contain any data regarding nominal power consumption. For the 6100E CSS, based

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TABLE 4-2. X.25 INTERFACE/6105 CC

Description	Purchase Unit Cost	Qty	Purchase Total Cost	Monthly Maintenance Unit Cost	Monthly Maintenance Total Cost	7-Year Life Cycle
Cabling						
EDDC Cable at 300 feet	180	4	720	n/a		
FAA Installation						
EDDC Cable at 20 feet (4 ports 8 hr/port)	45	32	1,440	n/a		
Tandem						
Tandem 6105-1 CC	4,118	2	8,236	22	44	
Paradyne DCX						
DCX X-GATE Cards	4,800	4	19,200	0	0	
DCX Chassis (16 Slots)	4,250	1	4,250	152	152	
Chassis Installation	250	1	250			
Cost Per Site			$34,096		$196	$45,170
Total Cost for 25 Sites			$852,400		$4,900	$1,129,250 ==========

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TABLE 4-3. OPERATIONAL COSTS

	Units	Modified EEM Alternative	X.25/6105 CC Alternative
Power Consumption			
Number of Units		3	2
Unit Consumption	(kW)	0.53	0.04
Total Consumption	(kW)	1.59	0.08
Utilization per Month	(Hours)	720	720
Energy Consumption	(kWh/Month)	1144.8	57.6
Prorate for 64 Ports of 180		407.0	
Unit Cost	($/kWh)	0.07	0.07
Total Cost	($/Month)	28.49	4.03
7 Year Life Cycle Cost	($)	1,610	228
Cooling			
Number of Units		3	2
Unit Consumption	(Btu/Hour)	4193	158
Total Consumption	(Btu/Hour)	12579	316
Total Consumption	(kW)	3.69	0.09
Utilization per Month	(Hours)	720	720
Cooling Efficiency	(%)	100	100
Energy Consumption	(kWh)	2654	67
Prorate for 64 Ports of 180		943.6	
Unit Cost	($/kWh)	0.07	0.07
Total Cost	($/Month)	66	4.67
7 Year Life Cycle Cost	($)	3732	264

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upon discussions with Computer Power Group, the consumed power is estimated at 0.53 kilowatt (kW) per unit.

The power consumption for the 6105 CC is only 40 watts per board. It was assumed, in computing the reduction in power consumption and associated costs, that:

    a. Operation is 24 hours per day and 7 days per week (720 hours per month).

    b. The 6100E CSS consumption is prorated to 64 ports.

    c. Power costs $.07 per kW-hour.

The monthly costs, as summarized in table 4-3, are $28 for the Proposed Modified EEM Configuration alternative and $4 for the X.25/6105 CC alternative. For a 7-year life cycle these costs equate to $1,610 (Proposed Modified EEM) and $228 (X.25/6105 CC) per site.

Since the 6100E CSS does not require a Class I computer room environment, it can be installed in a "communications room" environment, as defined by Tandem. The ambient air temperature in this communications room cannot exceed 38°C (100°F). A maximally configured 6100E CSS cabinet with 45 LIUs generates 12,758 British Thermal Units (BTUs) per hour. For the 6105 board, the heat dissipation requirement is only 158 BTUs per hour per board or 316 BTUs per hour for two boards. It was assumed, in computing the reduction in power consumption and associated costs, that:

    a. Operation is 24 hours per day and 7 days per week (720 hours per month).

    b. The 6100E CSS consumption is prorated to 16 LIUs supporting 64 ports.

    c. Power costs $.07 per kW-hour.

It is also assumed that the chiller efficiency is 100 percent. Since it will be somewhat less, the actual differences will be greater.

The monthly costs, as summarized in table 4-3, are $66 for the Proposed Modified EEM Configuration alternative and $5 for the X.25/6105 CC alternative. For a 7-year life cycle these costs equate to $3,732 (Modified EEM) and $264 (X.25/6105 CC) per site.

As shown in figure 4-1, the 6100E CSS cabinet is 33 inches wide, 32.2 inches deep, and requires a 30-inch service clearance for both the front and back doors. The floor space requirements measure:
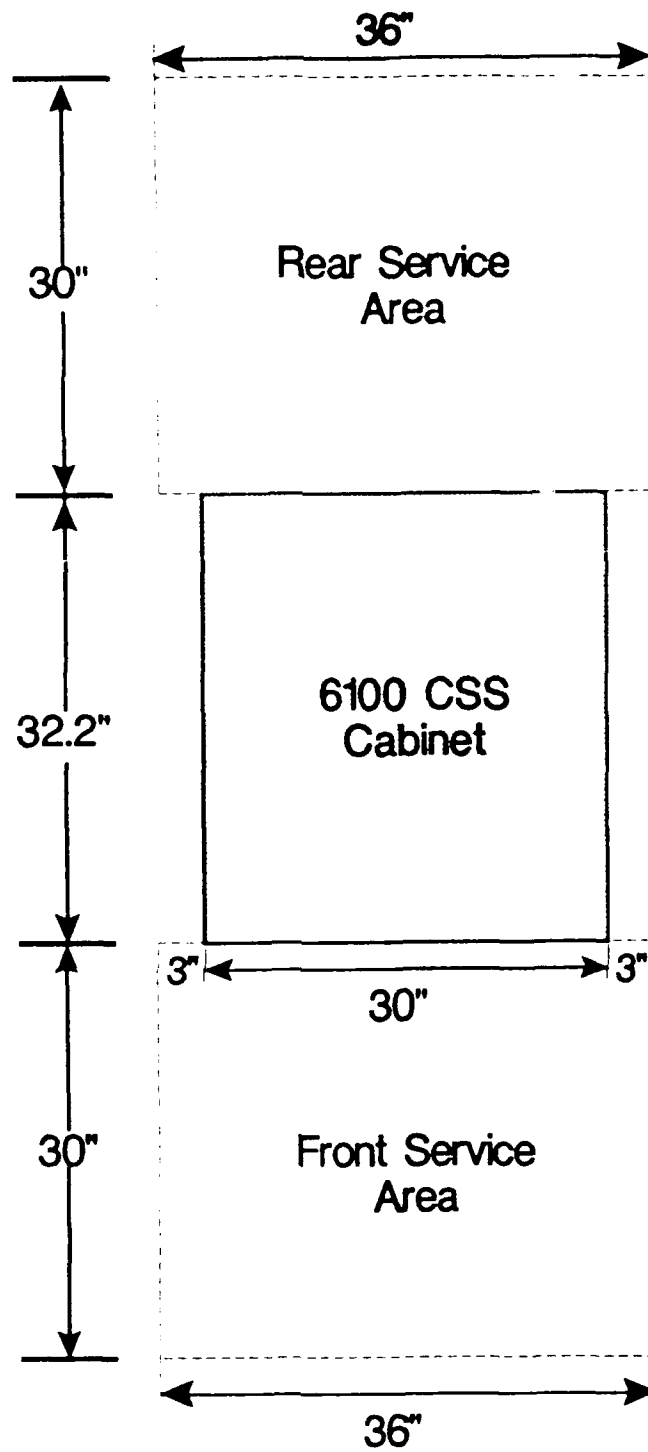
FIGURE 4-1. 6100E CSS FLOOR SPACE LAYOUT

a. 30 inches in width plus 1/2 of two 3 inch inter-cabinet gaps for a total of 33 inches.

b. 32.2 inches plus 30 inches for front and rear servicing for a total of 92.2 inches.

All three CSS units are contained in a single CSS cabinet. The floor space requirements for a 6100E CSS are approximately 21 square feet (33 inches x 92.2 inches) per cabinet. Since the 6105 CC cards reside in the MPS I/O chassis, no additional floor space is required. By using the 6105 CCs instead of a 6100E CSS, a reduction of approximately 21 square feet at each site can be achieved.

4.5 ANALYSIS OF MINOR IMPACT FACTORS.

This section investigates the sensitivity of the results of this analysis to changes in the following:

a. Tandem fiber upgrade versus fiber optic multiplexers.
b. Use of the 6100E CSS versus the 6105 CC.
c. Use of LIU1s versus LIU4s.

4.5.1 Tandem Fiber Upgrade versus Fiber Optic Multiplexers.

In order to move the 6100E CSS to the basement, the high speed connection between it and the MPS must be converted to fiber optics. Tandem's 6130 Fiber Optic Interface Field Upgrade can be used to convert the connection between the 6100E CSS and the MPS from copper to fiber optics. The cost of the field upgrade is $1,696 per line. Six lines need to be run between the MPS and the 6100E CSS (one for each BOB-CIU connection) at a total cost of $10,176.

An alternative connection method for the BOB-CIU connection is to convert the connection to fiber over the bulk of the distance between the MPS and the 6100E CSS. This can be done with a short copper connection between the CIU and a copper to fiber multiplexer, a 300-foot fiber span, a fiber to copper multiplexer, and a short copper connection between the second multiplexer and the BOB. The cost of each multiplexer is $298. Twelve are needed to connect the six fiber optic cables for a total cost per site of $3,576.

If the 6100E is moved to the basement, the most cost effective method of connection is the use of multiplexers rather than the Tandem field upgrade. This method, however, will reduce system fault tolerance and increase maintenance costs because 12 active components and their associated physical connections would be added to the system configuration.

4.5.2 Use of X.25 with the 6100E CSS versus the 6105 CC.

From table 4-4, the prorated purchase cost of the four LIU1 slots in the 6100E CSS is $8,021 with $55 per month for maintenance. The life cycle for the 6100E CSS is $11,128. From table 4-2, the 6105 CC purchase cost is $8,236 with $44 per month for maintenance. The life cycle cost for the 6105 CCs is $10,722. Although the alternatives have comparable costs, the 6105 CC is the better choice due to improved fault tolerance and reduced floor space requirements.

If the 6100E CSS is used, it must be placed in the basement and fiber optic connections must be made to the MPS on the first floor because this connection is running a Tandem proprietary protocol, not X.25. Copper connections can be made for the X.25 link from the DCX 850 in the basement to the 6105 CCs in the MPS I/O chassis on the first floor at a much lower cost. The copper connections are more reliable than the fiber optic connections because there are fewer active components (no multiplexers). With comparable costs, the 6105 CC option is the better choice due to improved fault tolerance and reduced floor space requirements.

4.5.3 LIU1s versus LIU4s in the 6100E CSS.

In the Proposed Modified EEM Configuration alternative, it was assumed that only LIU4s were used in the 6100. If all 45 slots in the 6100E CSS are filled with LIU4s, 180 ports will be provided at a life cycle cost of $709 per port.

The current 6100E CSS configuration uses 37 LIU1s and 8 LIU4s. This provides only 69 ports. When prorated on a per port basis, the life cycle cost of one port is $2,781.

The LIU1/LIU4 mix is a very inefficient use of the 6100E CSS in this application so the equipment acquisition cost in the Proposed Modified EEM Configuration alternative was computed using only LIU4s.

5. FAULT TOLERANCE ANALYSIS.

5.1 INTRODUCTION.

In this section the Proposed Modified EEM Configuration and the X.25/6105 CC alternatives are compared relative to their capability to handle failure conditions. In this analysis, the classes of failures considered were components supporting a single MPS-DCX 850 link and components supporting multiple MPS-DCX 850 links.

TABLE 4-4.   6100 CSS WITH X.25

Description	Purchase Unit Cost	Qty	Purchase Total Cost	Monthly Maintenance Unit Cost	Monthly Maintenance Total Cost	7-Year Life Cycle
Cabling						
RS-232 cables 20 feet	10	4	40	n/a		
Tandem 6130 Fiber Optic Interface Field Upgrade	1,696	6	10,176			
Duplex Fiber Cable 300 ft	350	6	2,100	n/a		
FAA Installation						
Fiber (6 ports, 6 Hr/port)	45	36	1,620	n/a		
RS-232 (4 ports, 2 Hr/port)	45	8	360	n/a		
Tandem 6100						
Base Cabinet and Unit A (15 slots)	12,602	1	12,602	119	119	
Unit B (15 slots)	9,014	2	18,028	92	184	
LIU1 Cards	1,325	37	49,025	7	259	
LIU4 Cards	1,323	8	10,584	7	56	
Total			90,239		618	
Prorate for 4 Cards			8,021		55	
Paradyne DCX						
Paradyne DCX Expansion						
Main Chassis	4,250	1	4,250	152	152	
Installation	250	1	250			
Expansion Chassis	3,000	0	0	101	0	
Total			4,500		152	
X-GATE Cards	4,800	4	19,200	0	0	
Cost per Site			$46,017		$207	$57,713
Cost for 25 Sites			$1,150,425		$5,175	$1,442,813

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Component failures that can cause each of these classes of failures are identified and their impact analyzed. Failures of components that are common to both alternatives and have the same effect for both are not considered.

Each alternative is relatively robust to failures for MDT service because neither the Proposed Modified EEM Configuration nor X.25/6105 CC alternatives has a single point of failure. Both the 6105 CC and the 6100E CSS have a primary and alternate path to two different MPS processors providing redundancy. In the Proposed Modified EEM Configuration alternative, ports are dedicated for directly connected printers resulting in single points of failure for directly connected printers. The X.25/6105 CC alternative, however, provides switching for both terminal and printer support. This alternative, therefore, has no single points of failure. All components of the 6105 CC and the DCX 850 in the X.25/6105 CC alternative are redundant. The X.25/6105 CC alternative will require only 12 physical connectors while the Modified Proposed EEM Configuration will require 128 physical connectors, reducing the number of potential physical connector failures. All components of the 6105 CC are redundant. All components of the 6100E CSS are redundant except for each LIU which is comprised of a CLIP and a LIM. The 6105 CC, therefore, is more fault tolerant because it provides a greater degree of redundancy than the 6100E CSS.

5.2 PROPOSED MODIFIED EEM CONFIGURATION ALTERNATIVE.

In this alternative, there are 64 RS-232 links between the 6100E CSS and the DCX 850. These links may fail due to a LSC failure in the DCX 850 or a LIU failure in the 6100E CSS. If one of these links supporting an MDT fails, then a connection can be established using another link, providing one is available. This will require the user to establish another connection. If all ports are being used, then the user of the failed link will be queued and will have to wait for repair. There is a higher potential for physical connection failures with this alternative because it requires 128 physical connections between the 6100E CSS and the DCX 850.

For directly attached printers, the links are dedicated rather than switched. If one of the links supporting a dedicated printer fails, then no switch over is provided according to the current EEM recommendation. Thus, the failure must be repaired or the dedicated line moved to another available port to restore service.

5.3 X.25/6105 CC ALTERNATIVE.

In this alternative there are four RS-232 links, two per 6105 CC, connecting the four X-GATE cards in the DCX 850 to the 6105 CC. These links employ the X.25 protocol. Failure of an X-GATE card in the DCX 850 or a LIU in the 6105 CC would cause failure of a link. All connections can be manually reestablished over another X.25 link, however, providing all four links have not failed. The

user will have to initiate reestablishment of these connections. Reestablishment may be completed from either end (MPS or MDT) of the communications link. After the connections are reestablished, there will be no loss of functionality. Performance may be degraded, however, because the remaining physical links will be supporting additional connections. If a single link fails, then the required 64 connections will be switched over to the remaining three physical links resulting in 21 or 22 connections per link. Since this is still less than the 32 virtual circuits per X-GATE card recommended by Paradyne, performance should be adequate.

In this alternative the only component which can cause a failure of multiple links is the failure of a 6105 CC. This would put two of the X.25 links out of service. The two out of service X.25 links, however, could be reestablished by manually switching the two cables to the two available ports on the functioning 6105 CC. If unable to perform this manual switch, in a worst case scenario, 64 connections would have to be supported over two X.25 links. This still would not exceed the 32 connections over a single link recommended by Paradyne.

6. PRELIMINARY TESTING.

A set of tests to empirically evaluate the alternative configurations was performed by AT&T Paradyne using the Tandem equipment located at the FAA Technical Center, Atlantic City International Airport, NJ. The purpose of these tests was to evaluate the relative compatibility of the Paradyne and Tandem products. The evaluation also included functionality, and to a limited extent, performance. In these tests, as shown in figure 6-1, the following configurations were used:

   a.   EEM recommended configuration
   b.   X.25 Interface with a 6105 CC
   c.   X.25 Interface with a 6100E CSS

These configurations were very similar to the alternatives illustrated in figures 3-1, 3-2, and 3-3. An LIU4 was used in the 6100E CSS for the EEM recommended configuration. The major difference between the configurations as discussed and the testing configuration was that the testing was done locally at the FAA Technical Center rather than across the FAA national DMN.

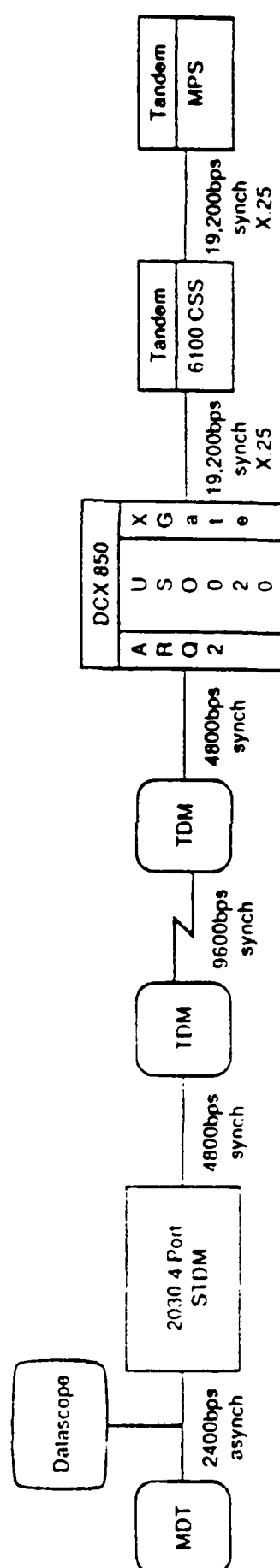The experiments were performed with three operators accessing the MPS software. After logging onto the MPS, the operators initiated a Log Summary Report (LSR) transaction. This involves sending an input message from the MDT with a length of approximately 10 bytes and receiving a 3400 byte response message from the MPS.
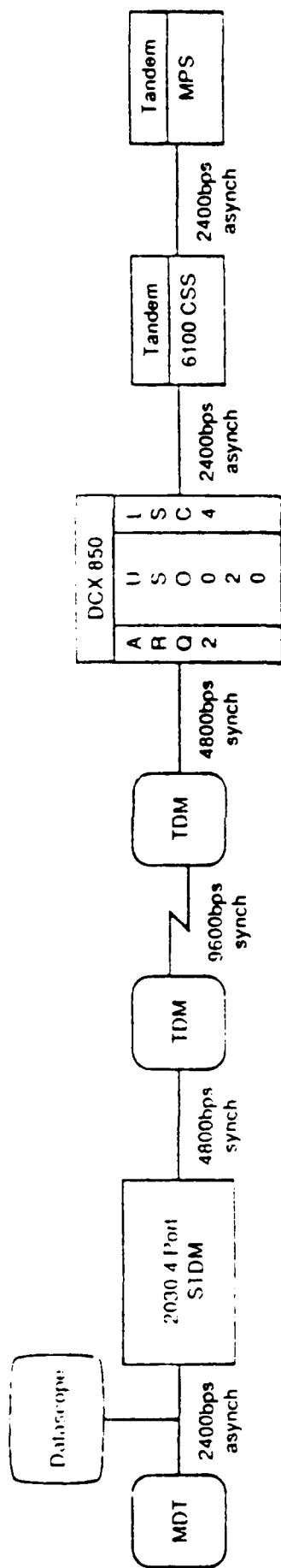
a) EEM
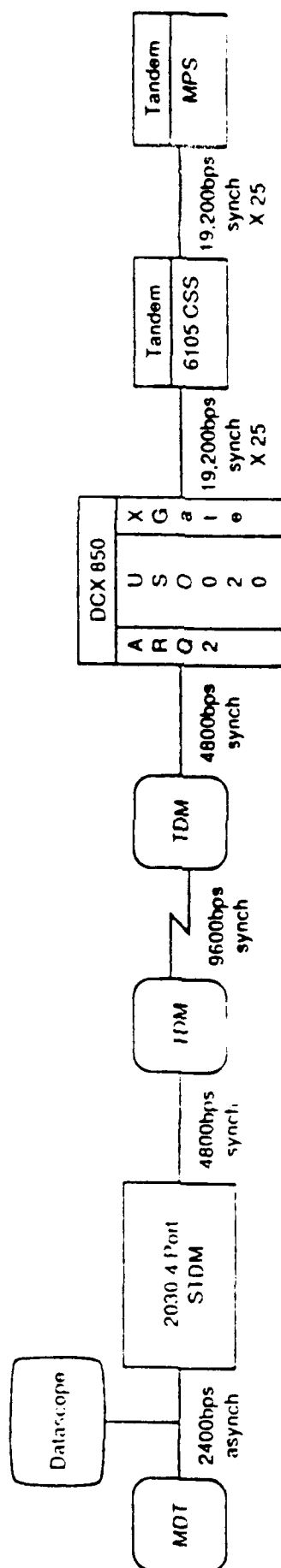
b) X.25/6105CC

c) X.25/6100 CSS

FIGURE 6-1. TEST CONFIGURATION

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The response message is sent in four separate segments. The transmission of the first three segments occurs concurrently with the applications processing. The transmission of the fourth and final segment occurs after the application processing has been completed.

As shown in figure 6-1, response time measurements were taken for each alternative by inserting a datascope between the MDT and the local statistical multiplexer. The datascope is a passive monitor which can be triggered on specific message fields and made to write a corresponding time stamp. Fields were selected to trigger the datascope at the beginning of an input message transmission and upon receipt of a corresponding response message. The difference between these time stamps is the response time for a particular transaction.

Processing in the MPS was monitored using the Tandem Viewsys utility. This utility provided the capability to view the process that was currently running. It also displays a timer such that the initiation time and termination time of a process could be measured and the elapsed time computed.

The results of the testing indicate that by using the X.25 interface:

   a.   The Paradyne and Tandem equipment are highly compatible.

   b.   Complete functionality of the MPS software is maintained.

   c.   A number of existing data control problems can be eliminated (see below).

   d.   Response time improved when tested with a statistically small number of users.

   e.   Response time is slightly improved with X.25 when using the 6105 CC versus the 6100E CSS.

In summary, use of X.25 is an improvement over the EEM approach although response time requires further analysis as discussed below.

With the existing system, it is necessary for the user to enter a Control-E when an MDT-MPS connection is being established. The existing system also has problems in clearing connections at the end of a session. Both of these problems are eliminated when X.25 is used with either the 6100E CSS or the 6105 CC.

For the initial screen, response time was found to be approximately 36-40 seconds using the EEM configuration and approximately 34-35 seconds using either of the X.25 configurations. For subsequent screens, the response times were 19-20 seconds using the EEM

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configuration and 16-17 seconds for either of the X.25 alternatives. The performance results should be regarded as preliminary because only a small number of users were employed in the test.

To analyze the impact on response, the individual elements of response time must be considered. These elements include:

a. Time to transmit the input message from the MDT to the MPS (T1).

b. Time to perform applications processing and I/O in the MPS (T2).

c. Time to perform communications processing in the MPS (T3).

d. Time to transmit the response message from the MPS to the MDT terminal (T4).

As discussed in the following paragraphs, the improvement is primarily in T4 while the other response time elements are roughly the same for all alternatives.

For the network transmission of the 10 byte input message, T1, there was some improvement in response time because the link between the DCX 850 and MPS operates at 19.2 kbps in the X.25 alternative and at 2.4 kbps in the EEM configuration. However, since the input message consists of only 10 bytes, this reduction is small (<< 1 second).

The application processing in the MPS, as determined by using Viewsys, is approximately 29 seconds for the initial screen. The I/O time in the MPS, T2, is approximately 1 second. These times were identical for all alternatives.

The communications processing times, T3, are different for the X.25 and EEM configuration. The differences are relatively small (typically < 1 second), however, and have no significant effect.

There are significant reductions in the transmission time of the response message from the MPS to the MDT terminal including:

a. The DCX 850-MPS link is faster because the X.25 link operates at 19.2 kbps rather than 2.4 kbps as in the EEM alternative.

b. The X.25 AM process in the Tandem which handles the X.25 protocol is more efficient than the TERMPROC process which handles the asynchronous links.

These advantages become significant because the output message is relatively long (3400 bytes). As discussed above, the response

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message is transmitted in segments described as T1, T2, T3, and T4. Since the first three segments are transmitted concurrently with applications processing, only the transmission time of the fourth segment, T4, will affect response time. Thus, the impact of the increased transmission speed affects only a portion of the complete transaction.

The measured results cannot be directly extrapolated to a large number of users because the 19.2 kbps link in the X.25 alternative is shared by multiple users while the 2.4 kbps link in the EEM alternative is dedicated to an individual user. For small traffic loadings, the X.25 alternative will experience less delay for the reasons previously discussed. There will be additional system overhead in the system with the X.25 link as more users log on and the rate of transactions being sent increases. In the EEM configuration the links are dedicated so no additional system overhead will occur. If, however, additional users are added to the 64 assumed, more physical ports must be included in the EEM recommendation. In the X.25 alternative, as the number of users increases, additional system overhead may be experienced. No additional ports are required until the system overhead becomes excessive. System overhead problems may be ameliorated by proper and judicious selection of band width.

The magnitude of the system overhead delays may be estimated from the workload. The worst case scenario involves messages moving from the MPS to the DCX 850. Let us assume that:

    a.   The average message size is 3400 bytes.

    b.   The average time between messages is 60 seconds.

    c.   There is a 15 percent overhead for headers and acknowledgments.

    d.   There are 16 user connections on each of the 4 X.25 links.

Based upon these assumptions, the corresponding throughput is 8.3 kbps. This would result in a utilization of the 19.2 kbps link of 0.43. At this utilization, additional system overhead should not be a problem.

The response time for X.25 using the 6105 CC is slightly less than that using the 6100E CSS with X.25. This occurs because 6105 CC is resident in the MPS backplane while the 6100E CSS is a stand alone device that must communicate with a CIU card in the backplane. Thus, there is an additional transmission between the 6100E CSS and the CIU which causes the added delay.

7. CONCLUSIONS AND RECOMMENDATIONS.

The results of analyzing alternatives to the Electronic Equipment Modification (EEM) configuration indicate that the X.25/6105 Communications Controller (CC) alternative produces the greatest benefits. This configuration realizes a significant cost savings, reduces the floor space required for equipment, and improves fault tolerance, functionality, and response time. The X.25/6105 CC alternative requires replacing the individual asynchronous connections from the Maintenance Processor Subsystem (MPS) to the multiplexer with a commercially available X.25 interface and replacing the Tandem 6100E Communications Subsystem (CSS) with the Tandem 6105 CC.

Equipment life cycle costs for acquisition, installation, and maintenance are reduced by $37,294 per site resulting in an overall cost savings of $932,350 over 25 sites based on a 7-year life cycle (see table 7-1). The major element of the life cycle cost reduction is the nonrecurring cost for equipment acquisition and installation which amounts to a savings of $25,147 per site or $628,675 overall. Replacing the 6100E CSS with two 6105 CCs reduces the cost for maintenance by $7,345 per site over the life cycle resulting in an overall savings of $183,625. Additional reductions in life cycle costs for power and cooling have been estimated at $4,803 per site cutting operational costs by $120,063 for the 25 sites.

The X.25/6105 alternative reduces the floor space required for the Tandem equipment. The 6100E CSS is a stand alone unit which requires 21 square feet of floor space. By replacing this unit with two 6105 CC boards which reside in the existing MPS I/O chassis, a savings of 21 square feet of floor space per site is achieved.

By virtue of the equipment operation and hardware redundancy, the X.25/6105 CC alternative provides a higher degree of fault tolerance. Should a failure occur on an MPS port supporting a direct connect printer, the communication path can be rerouted to another port by the X.25 interface resulting in no loss of service. In addition, if a DCX 850 port failure occurs, users will not be denied service because the communication paths affected by the failure can be multiplexed over the remaining ports. All components of the 6105 CC are redundant, where as the 6100E CSS contains components that are not, specifically, the Line Interface Units (LIUs) which comprises the Communications Line Interface Processor (CLIP) and a Line Interface Module (LIM). The 6105 CC, therefore, is more fault tolerant because it provides a greater degree of hardware redundancy than the 6100E CSS.

TABLE 7-1.   SUMMARY

	Modified EEM	X.25/6105	Difference
Per Site Nonrecurring			
Equipment Purchase	51,613	32,406	(19,207)
Equipment Installation	7,630	1,690	(5,940)
Per Site Recurring			
Equipment Maintenance	326	196	(130)
Operations (Cooling/Power)	94	9	(85)
Per Site Life Cycle			
Equipment	59,243	34,096	(25,147)
Equipment (Maintenance Only)	18,419	11,074	(7,345)
Operations	5,311	509	(4,802)
	82,973	45,679	(37,294)
Total Life Cycle			
Equipment	1,481,075	852,400	(628,75)
Equipment (Maintenance Only)	460,475	276,850	(183,25)
Operations (Cooling/Power)	132,775	12,725	(120,50)
	$2,074,325	$1,141,975	($932,350)

Benefit Description	Modified EEM	X.25/6105CC
Fault Tolerance	More points of failure	Fewer components, less points of failure
	CIU per path	Dual path on each 6105 card
Functionality	All MMS functions provided	All MMS functions provided
	Data control problems effect connection	Simplified connection management through elimination of data control problems
Performance	Satisfactory	Satisfactory
	No additional queueing at higher loads	Additional queueing at higher loads
		10% decrease in user rewponse time under load tested

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The benefits of the X.25/6105 CC alternative were extrapolated from preliminary tests conducted at the Federal Aviation Administration (FAA) Technical Center, Atlantic City International Airport, NJ. An empirical evaluation of the X.25/6105 CC alternative indicated that complete functionality of the MPS is maintained, a number of existing data control problems are eliminated, and response time was improved when measured in a testbed supporting three users.

Under these loading condition, a 10 percent improvement in response time was achieved. As the number of users being supported and the number of transactions increases, additional system overhead will be induced. However, system overhead problems can be ameliorated by proper, judicious selection of bandwidth.

In summary, use of the X.25/6105 CC alternative provides significant reductions in hardware acquisition and installation costs, reductions in power and cooling costs, increased availability of floor space, and an improved degree of fault tolerance. All of these benefits are achieved while maintaining MPS functionality, eliminating a number of existing data control problems, and maintaining or potentially improving user response time. Therefore, it is recommended that no additional 6100E CSS equipment be purchased, but rather the present configuration be replaced with the X.25/6105 CC alternative. At least two X.25 interfaces and 6105 CC controllers should be purchased for each site regardless of the number of lines actually used in order to maintain hardware redundancy. In order to increase virtual circuits and eliminate the need for expansion chassis in the multiplexer, it is recommended that further investigation be conducted into the use of V.35 as an alternative to the RS-232 standard.